# Micromechanical mirror mechanism as relay for integrated optics

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Abstract of **DE 19728598 (A1)**

The mechanism (1) has an actor element (8,9) allocated to spring element (5,6), whose longitudinal end is coupled to contacting electrode (3, 4) and which is used for holding a mirror element in a swivelable manner. The entire mechanism is located on a substrate (2) serving as base body.

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1. Micromechanical mirror (1) with a substrate (2), serving as bodies, with at least a stationary contacting electrode disposed on the substrate (2) (3; 4) with at least an elongated spring element (5; 6), with a mirror element (7), that over the spring element (5; 6) pivotable held is, and with at least an actuator element (8; 9) to the drive of the mirror element (7), characterised in that longitudinal end of the spring element (5; 6) with the contacting electrode (3; 4) connected is and the actuator element (8; 9) the spring element (5; 6) associated is.

2. Micromechanical mirror according to claim 1, characterized by an other contacting electrode disposed on the substrate (2) (3; 4), an other spring element (5; 6), its longitudinal end with the other contacting electrode (3; 4) and its other longitudinal end with the mirror element (7) connected is, and an other actuator element (8; 9), that the spring element (5; 6) associated is.

3. Micromechanical mirror after one of the preceding claims, characterised in that the spring element (5, 6) as elongated torsion bar formed is.

4. On an imaginary line (longitudinal axis 27) are appropriate for micromechanical mirror according to claim 3, characterised in that the two torsion bars.

5. Micromechanical mirror after one of the preceding claims, characterised in that the actuator element (8, 9) a spaced electrode disposed to the mirror element (7) at the spring element (5, 6) (14; 15) and an opposite counter electrode intended on the substrate (2) (16, 17, 18, 19) covers.

6. Micromechanical mirror after one of the preceding claims, characterised in that the actuator element (8, 9) two counter electrodes (16, 17, 18, 19) covers, whereby these two counter electrodes (16, 17, 18, 19) the directed electrode (14; 15) mirror-symmetrically to the spring element (5; 6) disposed is.

7. Micromechanical mirror after one of the preceding claims, characterised in that the substrate (2) below the mirror element (7) a recess (26) exhibits, whose base surface is large as those of the mirror element (7) and whose depth of the corresponding desired maximum turning angle a selected is.

8. Micromechanical mirror after one of the preceding claims, characterised in that the mirror element (7) two essentially rectangular formed mirror surfaces covers, which are mirror-symmetric to the longitudinal axis (27) of the spring element (5, 6) at this mounted.

9. Micromechanical mirror after one of the preceding claims, characterised in that the spring element (5, 6) and/or the mirror element (7) of silicon consist.

10. Micromechanical mirror after one of the preceding claims, characterised in that electrodes to the detection of the turning angle of the mirror element (7) provided are.

11. Micromechanical mirror after one of the preceding claims, characterised in that the two counter electrodes (16 to 19) of an actuator element (8, 9) gegenphasig or gleichphasig driven are.

12. Micromechanical mirror after one of the preceding claims, characterised in that the mirror element (7) different surfaces (28) to the colorselective reflectance of a light beam exhibits.

13. Method to the production of a micromechanical mirror (1) with a substrate (2), serving as bodies, with a mirror element (7), which pivotable held is, and with at least an actuator element (8; 9) to the drive of the mirror element (7) using a sacrificial layer, characterised in that the micromechanical mirror (1) at least a stationary contacting electrode disposed on the substrate (2) (3; 4) and at least an elongated spring element (5; 6) its longitudinal end with the contacting electrode (3; 4) connected is, exhibits that the mirror element (7) over the spring element (5; 6) pivotable held is that the actuator element (7; 8) the spring element (5; 6) associated is, and that the subsequent manufacturing steps become performed:

- Producing a sacrificial layer from porous silicon in the substrate (2) below a region, which lies in the mirror (1) below the movable parts, i.e. mirror element (7), spring element (5, 6) and actuator element (8, 9),
- Applying the contacting electrodes (3, 4) on the substrate,
- Growing up an epitaxial silicon layer on the sacrificial layer from porous silicon and
- selective removal as sacrificial layer from porous silicon to the production of the movable parts.

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The invention relates to a micromechanical mirror with a substrate, with at least a stationary contacting electrode with at least an elongated spring element, serving as bodies, with a mirror element, disposed on the substrate, which is pivotable held over the spring element, and with at least an actuator element to the drive of the mirror element, in accordance with preamble of Claim 1.

State of the art

Such micromechanical mirrors are known. They exhibit a mirror element, which is over a spring element, in particular a torsion bar, pivotable held on a substrate. Below the mirror element a recess is introduced into the substrate, so that the mirror element can implement an oscillation. The oscillation can be reached by means of an actuator element acting as electrostatic drive. The actuator element covers one from the outside with a voltage subjectable capacitor, whose becomes an electrode at the reason of the recess and its other electrode of the underside of the mirror element formed. Such Schwingspiegel becomes for example used as light modulators for displays and in the integrated optic as optical relays. Furthermore they serve as element for the Abscannen of a region in an interior space of a building or an automobile.

Since with an electrostatic drive formed by two capacitor electrodes the driving force depends to each other on the one hand on the electrode plate surfaces and on the other hand on their distance, a compromise between desired deflection of the mirror element and maximum possible capacitor voltage must be met with the known micromechanical mirrors. That is, by large distances of the plates large deflections are more achievable, however the necessary driving force for the mirror element can become only with comparatively very high electric voltages achieved. This can lead mirrors with micromechanical structures, in particular, to electrical isolation problems. However if low drive voltages come to the use, the distance between the capacitor electrodes, thus the mirror lower surface and the electrode, smaller selected, introduced in the recess, must become so that the necessary electrostatic driving force becomes achieved. Under the short distance between the capacitor electrodes however only a small deflection range of the mirror element results.

A such, would genericin accordance with-eat mirror with the features of the preamble of Claim 1 is from the EP 00 40 302 a2 known.

Furthermore a method is 13 disclosed to the production of a micromechanical mirror with the features of the preamble of Claim in the DE 195 47 584 A1.

Object of the invention is it to create a micromechanical mirror of the genericin accordance with-eaten type with which a large scan angle range of the mirror element is more achievable with simultaneous small power supply of the actuator element.

Advantages of the invention

The micromechanical mirror with the features of the claim 1 has the advantage that becomes provided by a spatial separation of actuator element and mirror a micromechanical mirror, which is characterised by a large scan angle range of the mirror element with small power supply of the actuator element. The spatial separation of mirror element and actuator element possible in particular a decoupling of the parameter choice, so that both elements optimum can be configured. The drive of the mirror element changes against it only to that extent the necessary torque becomes indirect over a portion of the spring element on the mirror element transmitted. Furthermore this coupling leads across the spring element to a swingable system, existing from mirror element, spring element and actuator element, which on use of the resonance frequency an enlargement of the scan angle possible. It is thus quasi a translation present, which can be varied depending upon division of the regions of the spring element between mirrors and actuator and between actuator and contact electrode. It is thus possible to divide the spring element in such a manner into regions that the region of the spring element between actuator element and mirror element is stronger tordiert due to the lively resonant vibration as the region of the spring element between contacting electrode and actuator element.

Furthermore an adjustment of the scan angle range of the mirror element can become by variation of the cross section of the spring element achieved. That is, in the cross section "thick" spring element a generated with the torsional vibration a larger resistance than a spring element thin in the cross section. It is thus more discernible that an interference of the swinging overall arrangement can become effected by appropriate selection and/or embodiment of the spring element.

By means of the rigidity relationship of the spring element, on the one hand by change of the cross section of the spring element and on the other hand by variation of the length of the two regions of the spring element, thus the amplitude increased height in the case of resonance can become affected.

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In a development of the invention is provided that is mounted on the substrate an other contacting electrode. With the contacting electrode an other spring element with its is longitudinal end a connected, whereby its other longitudinal end with the mirror element is connected. Preferably also this spring element an actuator element is associated. With this embodiment achieved becomes that the driving forces for the mirror element increased to become to be able, whereby a still larger scan angle of the mirror element is more achievable. On the other hand it is however also possible to supply the actuator elements in each case with an energy is smaller according to amount than with a drive with only a drive. It means that a smaller driving power for an actuator element becomes necessary. Furthermore an effected storage of the mirror element at two spring elements a precise oscillation deflection, so that deflections in undesirable directions become avoided.

In an other preferable embodiment is provided that the spring element is formed as elongated torsion bar, which can be tordiert by the actuator element. Preferably the two torsion bars lie on a common imaginary line; that is, that the torsion bars aligning.

In particularly preferable embodiment is provided that the actuator element covers a spaced electrode disposed to the mirror element at the

spring element and an opposite counter electrode planned on the substrate. Thus an electric drive for the mirror element realized becomes, that with a large deflection of the mirror element through - the previously mentioned translation - a small drive voltage required. Thus on the one hand an undesirable high heat development becomes avoided, on the other hand one no isolation problems arise in the case of short distances of the electrodes as a result of smaller electric voltages. Further it is particularly simple possible by an electric drive, the swinging arrangement, existing from spring element, electrode of the actuator element and mirror element to preferably shift with one alternating voltage into an oscillation whereby the waveform can become selected depending upon requirement. Of course also a pulsed DC voltage can be as drive voltage provided.

Further an electric drive offers the advantage with two actuator elements that a deflection of the mirror element is in a second direction possible. This becomes possible if the actuator elements become gegenphasig, i.e. operated with drive voltages, which are phase shifted to each other. It is thus possible to shift the mirror element into an oscillation by the longitudinal axis of the spring elements and an other oscillation, which runs preferably vertical to the first oscillation to overlay. By appropriate selection of the drive voltages, in particular by a phase shift, will it thus possible to move the mirror element in two dimensions i.e. on the one hand into a torsional vibration around a mirror longitudinal axis and on the other hand into a second torsional vibration (relaxation oscillation) around a mirror transverse axis. If a light beam meets a mirror surface with a such deflection of the mirror, then the light beam becomes the corresponding oscillation frequency of the mirror in two dimensions deflected. A projection of this beam on a surface results in a Lissajous fig. The corresponding ratio of the frequencies of both oscillations can take place a sampling of a surface or a space. The sampling can besides still substantial fine dissolved become, if the two oscillations are phase shifted to each other. By will it possible scanning a space or a surface in such a manner that almost no unabgetasteten regions in the space result.

In one preferable embodiment particularly is provided that the actuator element covers two counter electrodes, whereby these two counter electrodes the associated electrode is mirror-symmetric disposed to the spring element. By the fact it becomes possible that a drive of the mirror element becomes in such a manner realized, so that the torsional vibration and/or the torsional vibration in both rotational directions becomes forced. That is, the mirror element is expenditure-steered in both rotational directions and reset, so that a mechanical restoring force of the spring element becomes overcome and/or supported. Thus a particularly uniform torsional vibration of the mirror element can be obtained.

In a development of the invention is provided that the substrate exhibits a recess, whose base surface is larger as those of the mirror element and their depth the corresponding desired maximum deflection selected below the mirror element. It is thus possible to arrange the mirror element in a small height to the substrate whereby a sufficient large deflection of the mirror element is ensured nevertheless.

In preferable embodiment is provided that the mirror element covers two essentially rectangular formed mirror surfaces, which are mirror-symmetric to the longitudinal axis of the spring element at this mounted. By will it possible extending the region of the spring element between the actuator element and the mirror element whereby the maximum deflection of the mirror element can become increased with excitation with resonance frequency, since this extended region of the spring element can be tordiert opposite a shorter embodiment substantial stronger.

Preferably the surface of the mirror element can be differently formed. On the one hand it is possible to implement the mirror element as pure mirror on the other hand one the surface can be in such a manner constituted that a filtration of the light becomes made. For example at least a Spektralfarbe of the light beam can be filtered.

Other embodiments result from the Unteransprüchen.

The invention relates to furthermore a method to the production of a micromechanical mirror, according to claim 13, which are characterised by it that becomes generated on a substrate porous silicon, below a region, which lies in the micromechanical mirror below the movable parts, i.e. mirror element, spring element and actuator element. Subsequent ones become the contacting electrodes on the substrate applied. On the porous regions of the silicon further an epitaxial layer, preferably silicon, is grown up, whereby subsequent selective removal of the porous silicon leads to manufacturing the movable parts. Thus achieved becomes in advantageous manner that a mirror can become realized, which consists of mono or polycrystalline silicon. Thus in particular the surface of the mirror element can become in such a manner affected that no Oberflächenwölbungen or roughness are present, so that a light beam with high efficiency can become exact deflected. A so generated micromechanical mirror finds in particular in scanning optical components, for example bar code readers or space control members, application.

Drawing

The invention becomes more near explained on the basis an embodiment with reference to the drawing. Show:

Fig. 1 a micromechanical mirror,

Fig. 2 the micromechanical mirror in accordance with Fig. 1, whereby the mirror element from its basic position is expenditure-guided and

Fig. 3 the micromechanical mirror in accordance with Fig. 1, whereby the mirror element from its basic position is expenditure-guided.

In Fig. 1 is a micromechanical mirror 1 shown, on a substrate 2, in particular silicon, serving as bodies, formed is. The mirror 1 covers contacting electrodes of 3 and 4, two spring elements 5 and 6, essentially rectangular formed mirror surfaces an exhibiting mirror element of 7 as well as two actuator elements 8 and 9.

The contacting electrodes 3 and 4, the spring elements 5, 6, the mirror element 7 as well as the actuator elements 8, 9 are mirror-symmetric to longitudinal axis 27 (mirror longitudinal axis) and to to longitudinal axis 27 the rectangular longitudinal axis 27 ' (mirror transverse axis). Both axes lie in a common parallel plane disposed to a top 2 ' of the substrate 2.

The contacting electrodes 3 and 4 are stationary 2 disposed on the substrate and form attachment points 10, 11 for the spring elements 5 and 6. The spring elements 5 and 6 are 4 formed with one their longitudinal ends in each case at the attachment points 10, 11 mounted and/or integral with the contacting electrodes 3 and. The spring element 5 is with its longitudinal end at the region 12 of the actuator element 8 disposed and/or integral with this formed and carries to its other longitudinal end the mirror element 7. Therefore a spring element section becomes 20 formed, which is thus between the actuator element 8 and the mirror element 7.

The actuator element 9 and/or its region 13 a spring element section 21 with the region 13 performed integral associated with its longitudinal end and/or is. At its other longitudinal end the spring element section 21 carries the mirror element 7. Easily is apparent that the spring elements become 5 and 6 by the spring element sections 20 and 21 as well as 23 formed by spring element sections 22 and in each case, whereby the spring element sections are 22 and 23 between the associated actuator element 8 and/or 9 and the associated contacting electrode 3 and/or 4 formed in each case. Preferably the contacting electrodes 3 and 4, the regions 12 and 13, are the mirror element 7 and the spring elements 5 and 6 integrally formed.

The spring elements 5 and 6 in each case an actuator element is 8 and/or 9 associated, whereby laminar regions 12, 13 each 14 and 15 form

one electrode and preferably integral 6 performed with the associated spring elements 5 and/or are. Below the electrodes 14 and 15, which preferably exhibit a smaller surface than the mirror element 7, is two counter electrodes each 16, 17 and/or 18 and 19 on the substrate 2 formed. The counter electrodes 16 to 19 exhibit in each case connecting elements (not shown), which are 2 formed on the substrate and make possible an electrical connection. The electrodes 14 and/or 15 are over their associated contacting electrodes 3 and/or 4 and 6 electrical over the associated spring elements 5 and controllable. Therefore becomes by the electrodes 14 and 15 as well as the counter electrodes 16 to 19 capacitive structures, thus capacitors c1, C2, C3 and C4 formed, whereby the capacitors c1 and C4 the actuator element 8 and the capacitors C2 and C3 the actuator element are 9 associated.

The substrate 2 exhibits recesses 24, 25 and 26, whereby 17 mounted at the reason of the recess 24 the counter electrodes are 16 and. Corresponding one applies to the recess 26, i.e., on their bottom the counter electrodes are 18 and 19 disposed.

The recess 25 is appropriate - toward the longitudinal axis 27 seen - between the two recesses 24 and 26 and is for the mirror element 7 associated. The recess 25 exhibits a base surface, which is large as the base surface of the mirror element 7, so that the mirror element can immerse 7 into the recess 25 swivelingmovable. The depth of the recess is dependent, i.e., of a maximum desired scan angle, the per deep recess 25 into the substrate 2 introduced, the scan angle of the mirror element 7 selected is the larger can become.

It is more discernible the fact that the mirror element is 7 6 freemoving suspended with the preferably rod-shaped spring elements 5 and and with a torsion of the spring elements, in particular the spring element sections 20 and 21, around the longitudinal axis 27 can turn. The depth of the recess 25 is to be affected thereby preferably so dimensioned that the mirror element 7 can be expenditure-steered for example around +-30 DEG, without thereby the substrate 2, thus a bottom of the recess 25.

So that the mirror element can become 7 offset into a rotational movement, the actuator elements become 8 and 9 in each case applied with an electric voltage, which leads the capacitors formed electrodes to a reduction or an enlargement of the distance that. Since force spaced is appropriate on the electrode the 14 and 15 to the longitudinal axis 27 of the spring element 5 and 6, a torque becomes applied on the spring elements, which causes the rotational movement of the mirror element 7. Whereupon is on the basis Fig. 2 to be received more in greater detail.

The Fig. the micromechanical mirror 1 shows 2, whereby equal parts - as in Fig. 1 shown - are provided with same reference numerals. Without a repeated description of these parts therefore one does.

Easily is in Fig. 2 apparent that the mirror element is 7 27 rotated around the longitudinal axis. In order to reach the rotational movement of the mirror element 7, the capacitors C3 and C4 become in such a manner with voltage applied that between their electrodes 14 and/or 15 and their counter electrodes an attraction effect adjusts itself 17 and/or 19. This can become by the fact achieved that the electrical charges on the electrode are gegenpolig 14 and/or 15 and the associated counter electrodes 17 and 19.

If the mirror element is to become into the other direction rotated, then the electric voltages at the capacitors c1 and C2 become in such a manner applied that with these the attraction effect arises.

It is however also possible to put on the respective electric voltages pulse-type so that at the capacitors c1 and C2 as well as C3 and C4 the attraction effect alternate adjust themselves. Thus the mirror element alternate becomes into and the other direction around the longitudinal axis 27 the rotated, therefore implements the mirror element 7 a torsional vibration movement. Manners the electric voltages a pulse frequency up, which corresponds to a mechanical resonance frequency of the swinging arrangement, existing from mirror element 7, spring element 5 and 6 and the laminar regions 12 and 13, becomes in particular the mirror element 7 into a resonant torsional vibration offset. Because the drive in the region of the mechanical resonance frequency made, in such a manner expenditure-steered the mirror element 7 in its torsional vibration that at least the spring element sections 20 and 21 are tordiert. Thus achieved that the mirror element can re-paint over 7 large scan angles it will be expenditure-steered, however the regions 12 and 13 of the actuator elements 8 and 9 not very strong.

It is thus a type translation provided, which can become 23 set by choice of the aspect ratio between the spring element sections 20 and/or 21 and 22 and/or. That is, the per prolonged spring element sections 20 and 21 in relation to the spring element sections 22 and 23 is, the larger is the scan angle of the mirror element with constant deflection of the actuator elements, since the longer spring element sections 20 and 21 can be tordiert stronger. It is shown thus that the mirror element can be expenditure-steered 7 substantial strong as the actuator elements 8 and 9. By the fact it becomes possible that a light beam hitting on a surface 28 of the mirror element (not shown) can become stronger substantial as with the mirrors deflected known in the conditions of the technique. Therefore a large scanning area results in the case of the use of the micromechanical mirror 1, for example as scanning element. Further achieved becomes by the translation that the distances between the single electrodes of the capacitors c1 to C4 of small selected to become to be able, so that a relative small drive voltage can become provided, whereby on the one hand a small power dissipation of the actuator elements 8 and 9 arises and arises on the other hand by the low drive voltage no isolation problems, i.e., tension estimates between the single electrodes of the capacitors c1 to C4 become avoided.

Therefore those can preferably exhibit the actuator element 8 and/or 9 associated recess 24 and/or 26 a smaller depth than the recess 25. The smaller depth of the recesses 24, 26 results also from an extension of the actuator elements 8, 9 shorter opposite the mirror element 7 toward to the axis 27 '. Therefore the scan angle of edge regions of the actuator elements is a 8, 9 corresponding small.

Furthermore it is favourable that by the large distance between mirror element 7 and the bottom of the recess 26 a relative small air friction is during the torsional vibration present, so that the micromechanical mirror can become 1 operated with ambient air pressure. It must become thus no air evacuation in an a living (not shown) made, is 1 preferably housed in which the micromechanical mirror.

In Fig. 3 is the micromechanical mirror 1 shown, whereby equal parts as in the Fig. 1 and 2 also here is provided with the same reference numerals, so that to the associated description can be referred.

Easily is in Fig. 3 apparent that the mirror element 7 of an other deflection is subjected. This deflection becomes achieved thereby that the capacitors become c1 and C4 with a gleichphasigen voltage applied, however opposite the voltage, which is gegenphasig the capacitors C2 and C3 supplied. Thus a light beam in an other direction deflected, reflected of the surface 28 of the mirror element 7, can become. The mirror element 7 knows thus a rotational movement, in particular a tilting movement, around the axis 27 ', implements, the spring elements 5 and 6 work quasi as bending bars.

It is of course also possible to subject the actuator elements 8 and 9 in such a manner with electric voltage that both the torsional vibration in accordance with Fig. 2 and the rotational movement in accordance with Fig. 3 7 performed simultaneous of the mirror element becomes. The for example made drive in such a manner that alternate become preferably with high frequency the actuator elements 8 and 9 with a voltage applied, which causes the torsional vibration around the longitudinal axis 27 and simultaneous supplied with a voltage becomes those the rotational movement around the axis 27 ' effected. Manners these drive voltages, an integral frequency ratio to each other up and are stacked the oscillations of the mirror element 7 vertical caused thereby, a so projected light beam a so called Lissajous fig reflected of the surface 28. The projections of the light beam, thus the Lissajous fig, still by the fact changed can become that the oscillations (torsional vibration and rotational movement) exhibit a phase shift to each other. Thus can be produced a variety of such Lissajous figs, so that a region which can be scanned can be almost completely abgescannt. Meant, the corresponding frequency ratio and the phase shift of the

oscillations and/or drive voltages such a diverted light beam scannt to each other for example a space particularly intense off, so that can become achieved in advantageous manner an essentially complete monitoring of the space.

It is of course also possible to supply the actuator elements 8 and 9 with drive voltages which exhibit a small frequency. Thus the mirror element 7 can be expenditure-steered more stationary, i.e., a drive is in such a manner possible that the mirror element 7 in a desired moving position remains.

Further the micromechanical mirror 1 at least an other electrode pair (not shown) can be associated, which preferably also the spring elements is 5 and 6 associated. One to this electrode pair applied voltage changed their value with the deflection of the mirror element 7. This voltage is known with the help of an evaluation device more detectable, so that the scan angle of the mirror element can become 7 certain at any time, therefore is the direction of the reflected light beam.

In the following a simplified expiration of manufacture of the micromechanical mirror becomes 1 described:

First porous silicon generated, at the locations, becomes at those in a later manufacturing step the movable parts, i.e. the mirror element 7 on the substrate 2, which preferably consists of silicon, at locations of the substrate 2, which become spring elements 5 and 6 and the actuator elements 8 and 9, applied. Subsequent ones become the contacting electrodes 3 and 4, preferably from polysilicon, on a laid on, for example from TEOS existing and as sacrificial layer serving insulating layer applied. Subsequent ones can be grown up on the porous silicon an epitaxial silicon layer at those locations, because of which the movable parts are to be. If the porous silicon is complete or partial oxidized, the epitaxial silicon layer becomes performed as polycrystalline layer, which lends a diffuse reflecting surface to the mirror. With not oxidized porous silicon the epitaxial layer is monocrystalline, whereby the mirror surface is flat and no light faithful effects caused. Thus a light beam can become essentially dispersion-free reflected. The movable parts, in particular the mirror, can become thus depending upon requirement out poly or monocrystalline silicon prepared. A subsequent removal of the porous silicon layers below this epitaxial silicon layer lets develop in particular the recesses 24 to 26. Alternative ones can become also etching methods selective undercutting of the mirror and the other movable parts used, for example can so called KOH corroding used become.